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ARTICLE I. *On the Physical action of Capillary Systems.—Identification of the force producing motion with the chemical force.* By JOHN W. DRAPER, M. D., Professor of Chemistry and Physiology in Hampden Sidney College, Va.

1. It has been alleged, as a bar to all physiological investigation, that the phenomena of life are of so peculiar a nature, that we must necessarily forever remain ignorant of their causes; that, unlike physical phenomena, which are of a simpler caste, and more within the reach of human understanding, there is something in these inherently mysterious and incomprehensible. This unphilosophical impression exists not only in the minds of the vulgar, but has extended itself to men well trained to scientific research: it is to be found in the writings of the most eminent physicians, and often affords a plausible screen for professional ignorance. Of all the sciences, medicine is the last to profit by the analytic method—a method which has raised other departments of knowledge to their present rank. Its cultivators pursue the same course of synthesis which was pursued in the days of the Greeks—they reason from hypothesis to fact, instead of from fact to hypothesis.

2. It may, however, be boldly averred, that the science of life is not more occult than any other of the sciences. We may, by proper investigation; carry it as far; and in the pursuit we shall only stop short at the very same point which has proved impassable in them.

Of final causes we know nothing; the immediate agent of life is not more obscure than any of the remote physical agents. If we cannot assign any reason why a seed germinates, can we tell why a stone falls to the earth?—is the one phenomenon any more comprehensible than the other? If we cannot tell how it is that one parent should produce a countless offspring, each of which has the power of reproducing beings like itself, neither can we tell how a spark produces an extensive conflagration. It avails us little to say that the principle of life, like the principle of heat, possesses a radiant character, or has a power of self-production. We are equally ignorant how the wide spreading flame results from a spark, and how countless myriads of seeds have originated from one primordial germ.

3. Some parts of the science of physiology are doubtless within the reach of scientific investigation. Most of the functions of organic life are of this character. Absorption, secretion, circulation, and respiration are carried on through the medium of tubular arrangements of different kinds, endued with specific powers. We are not well informed of the nature of these actions, or of the force giving rise to them. The changes taking place in organic structures partake partly of a mechanical, partly of a chemical aspect, bearing some similarity to other physical changes effected by known agents, yet not identical with them. Some have supposed that the attraction of affinity, or the force of capillarity, was the power in question, operating in an unusual manner, under unusual circumstances; but the majority of medical writers have cut the knot, instead of untying it, and assert that it is a peculiar force, recognised under the title of vital force, life, or nature.

4. It is, however, most unphilosophical to resort to these vain explanations, which after all afford us no information, substituting only obscure terms as the causes of events not more obscure. Had we approached the problem of pore-action in the same spirit that has led to the development of the causes of magnetic action, a similar and equally striking advance would have been made.

5. Capillary attraction, considered simply as a mechanical force, is not competent to produce those changes which the pores and narrow cylinders of organic structures give rise to. The products of glandular action are chiefly compounds of a definite number of equivalents, bearing a strong resemblance to the products of ordinary chemical action; but still the operation of capillarity as a force producing motion is undeniable. Can it also produce chemical changes? Is it simply a manifestation of the electro-chemical relations of matter?

6. Previous to entering at large into an examination of the laws of pore-action, this query will demand an answer. We shall find from what follows, that capillary attraction is a force nearly allied to, if not identical with, chemical affinity. Now, the investigation of the problem of pore-action naturally divides itself into two parts. 1st. The mechanical conditions of equilibrium and movement of fluids residing in tubes of narrow diameter, but of any length. 2nd. The chemical changes which fluids so situated undergo.

7. The identification, therefore, of the force producing the mechanical effect, with that producing the chemical changes, is a most important point, and to this I shall direct my attention in the present communication.

8. There are two phenomena of capillary attraction, the conditions and circumstances of which are well known—the rise and depression of fluids in tubes of a certain diameter, and the adhesion of flat solid plates to the surface of fluids. From the former of these this kind of attraction has derived its name; the latter furnishes us with the means of making researches, devoid of ambiguity, in reference to the physical cause of capillarity.

9. If a circular disk of glass, or any other solid substance, *Fig. 1*, *a b*, be placed on the surface of any fluid, *e f*, by means of a handle *c*, it will adhere thereto with a certain force, which may be measured by means of a balance, but which is sufficiently evident when attempts are made to lift the disk with the hand. This force is known under the name of capillary attraction. An investigation of its physical cause, and the laws respecting it, involve the fundamental propositions of pore-action and passage through tissues.

10. The phenomena of capillarity are brought about by electricity, operating under peculiar circumstances. They are due to a disturbance of the electric equilibrium, and hence are intimately allied to all kinds of chemical and vital changes.

11. Let *a b*, *Fig. 2*, be a glass plane, reposing on the surface of mercury, *c d*, contained in an insulated vessel, and capable of being elevated by an insulating handle *e*; let the mercury be connected with an electrometer *f*, by means of a wire. Now,

so long as the glass plane and the mercury are in contact, the electrometer evinces no disturbance; but

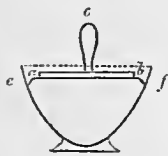


Fig. 1.

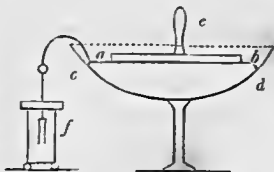


Fig. 2.

as soon as the plane *a b* is raised by its insulating handle, electricity is instantly developed, and the gold leaves diverge. As there was no electrical excitement whilst the plane and the metal were in contact, it is a legitimate inference that the electricity now developed was the cause of their strong attraction or adhesion; and this is corroborated on taking the glass plane to another electroscope, when it will be found that it is electrified positively and the mercury negatively; and that consequently when they are brought into the vicinity of each other, a powerful attraction *must* result.

12. A cause of attraction being thus developed, it would be very unphilosophical to seek for other agencies where one so competent to produce all the effects is observed to exist. For in every case where a solid plane reposes on the surface of a fluid not wetting it, a large amount of electricity of very high tension is produced, the electricity of the surface of the plane being always opposite to that of the liquid. *They must therefore attract each other.* I express here only a fact, not involving any disputed hypothesis whatever, as to whether that development of electricity originates in the mere contact of the bodies, their chemical action, or any other cause; but it is a fact, that when any solid reposes upon any fluid, provided its surface does not become wetted, a development of electricity uniformly takes place, and a powerful degree of attraction must necessarily ensue.

13. The postulate here introduced requires explanation, for electric excitement is not observed if the solid surface is wetted. Solids bear a peculiar relation to liquids, being wetted or not wetted by them. Most solids, for instance, are wetted by water, and but few by mercury; the surface of the glass is readily moistened by alcohol or oil, but not by melted sulphur or mercury: hence the latter, from its not adhering to the skin, was called by the older chemists *aqua non madifaciens manus*. The circumstance, that no electrical excitement is observed when a solid surface is wet, might appear at first sight contradictory to the hypothesis here assumed. A more accurate examination, however, places it in a very different light, and shows that the phenomena observed are exactly such as they ought to be hypothetically. If a disk of glass is placed on the surface of water and then removed, the gold leaves of the annexed electroscope are not affected, for, strictly speaking, no rupture has taken place between the solid and the fluid; the thin film of the latter in contact with the former still remains so: it is only the cohesion of the watery particles that is overcome, not the adhesion of the solid to the fluid, and hence no electrical development appears.

14. Geometers have shewn the exact relation a solid must bear to

a fluid to be wetted by it. It results from the mathematical investigations of CLAIRAULT, that if the attraction of the particles of the solid for those of the fluid is more than half the attraction of these last for each other, the solid will be wetted; but if it be less than half, the solid will not be wetted. An experimental proof of this may be ob-

tained by counterpoising a disk of glass *a, a*, Fig. 3, at the end of one of the arms of a balance, by weights in the scale *b*, and then lowering it on the surface of some mercury in a cup *c*; it will be found that a certain weight must be added in the scale *b* to detach it. Next in place of the disk of glass, substitute a

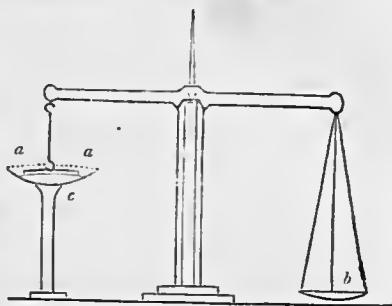


Fig. 3.

plate of *amalgamated* copper, of the same size and weight, and ascertain the force required to detach it; this will uniformly be found more than double the former weight. The first weight expressed the attractive force existing between a surface of glass and mercury; the second the cohesion of a cylinder of mercury of the same diameter, and the numbers obtained experimentally corroborate the investigations of Clairault.

15. I dwell on this part of the phenomenon because it is of no small importance; the same conditions that determine whether or not the surface of a solid is to be wetted, determine also whether a liquid shall pass through a pore, and move forward in a capillary vessel.

16. The difficulty arising from the non-development of electricity, where the solid surface is wetted, being thus dismissed, we next enquire whether the hypothesis here assumed will give numerical results analogous to those procured by experiment. In other words, if two solids which adhere to a certain fluid, with forces differing in amount, develop upon rupture, quantities of electricity in the same ratio. As a general result, the balance and electrometer prove that this is the case. Beeswax, which adheres to mercury with much less force than gum lac, develops likewise much less electricity. Gum lac, which adheres less strongly than glass, likewise develops much less electricity; but when we attempt to run a comparison in this manner along a series of substances, we find there are many disturbing causes, which in most cases incapacitate us entirely from making comparable results.

Much depends on the relative conducting power of the surface employed. A plate of iron may be separated from a surface of mercury, which does not wet it, with a very small disturbance of electric equilibrium, arising from the high conducting power of the metallic plate, which enables a transfer of any free electricity to take place if the plate should tilt on one side, or any thing affect its horizontality during the act of separation. In proportion as the conducting power increases, although the force of adhesion may remain the same, the total effect on the electrometer should diminish; and this is agreeable to experience. Again, the presence of moisture on any part of the touching surfaces will vitiate the results; partly owing to its high conducting power, but chiefly to the circumstance that it hinders the surfaces under trial from ever coming into contact.

17. The circumstance of this great variability in the amount of developed electricity, is in itself strong evidence of relationship between the supposed cause and the effect. Gay Lussac found that it required a weight sometimes of 158 and sometimes of 296 grammes, to detach a certain disk of glass from mercury, depending on causes which were not very apparent. An effect thus differing in amount indicates a cause of like variability, or subject to many disturbances.

18. I assume, therefore, that the agent bringing about capillary phenomena is identical with that producing chemical action, and that both may be referred to electricity. The force of cohesion bears the same relation to both, acting on both as a disturbing power. Nay, we may even take a much more extensive view of the matter; and from the ratio these forces bear to each other, predicate the effect of their combined action, which may be classed under three distinct heads.

1stly. If the force of attraction of the particles of a solid, for the particles of a fluid, be not equal to half the cohesive force of the latter, for each other, the fluid will refuse to pass through a pore of that solid substance; and in capillary vessels consisting of it, will be depressed below its hydrostatic level.

2ndly. If the force of electric attraction of the particles of a solid, for the particles of a fluid, exceeds half the cohesive force of the latter for each other, but is not equal to the whole force, the fluid will pass through a pore formed of that solid substance, and in a capillary tube of it, will rise above its hydrostatic level.

3dly. If the force of electric attraction of the particles of a solid for the particles of a fluid, exceed the whole cohesion of the latter, *chemical union* ensues.

19. In thus assimilating the force producing pressure on planes,

and motion in narrow pipes, with the force producing chemical changes in the constitution of bodies, a great advantage is gained in simplifying physiological investigations in respect of the action of capillary systems. It is an electrical force that determines all kinds of constitutional changes developed in bodies by the chemistry of organic life, and it is a manifestation of the very same force that carries some fluids along the almost invisible vessels of living structures, and denies to others a passage. All the phenomena of inorganic chemistry are the result of the balancings of the force of cohesion on the one hand, and electrical attraction on the other. If Berthollet was wrong in supposing that chemical affinity as an acting force had no existence, other chemists have equally erred in supposing that all kinds of changes, without any limitation, were due to it. Whether we investigate the phenomenon of chemistry or of capillarity, we have the same forces to deal with, acting as antagonists to each other; and hence the whole effects imputed to capillary attraction may be regarded as belonging to that extensive class which the science of chemistry considers.

20. There is a variety of facts recorded by writers on capillary attraction, which an application of these principles readily explains, though hitherto they have been regarded by philosophers as remarkable anomalies. Such is the observation of HUYGENS, that it was possible to cause mercury to stand in a barometer seventy inches high; or that of P. ANAT, of a singular deviation in the hydrostatic level of the same fluid in different branches of a syphon.

21. The force of attraction which produces pressure, when plane solids repose on the surfaces of fluids, under other circumstances produces motions of various kinds. If a tube of small diameter be plunged into a liquid, the level within the tube does not correspond with that outside, except under very peculiar and very unusual circumstances; but sometimes the liquid rises far above its level, and sometimes it is depressed, the amount of disturbance taking place in both cases being in the inverse ratio of the diameter of the tubes. All fluids which can wet the surface of a narrow pipe rise in it; those which cannot wet it are depressed. Geometers have shown, that if the attractive force exerted by the pipe upon the liquid be more than half the cohesion of the particles of the latter for each other, there will be a rise; if it is equal, the level of the fluid inside and outside of the pipe will be the same; and if it be less than half, there will be a corresponding depression. Now, extensive observation proves that these three cases are always accompanied with certain peculiarities, as respects the surface of the fluid in the tube, as is represented in

Fig. 4. In every case where the fluid rises, it is observed to be terminated with a surface concave upwards, as appears at *a a*; if the level is the same as it should be hydrostatically, then the terminating surface is a plane, as at *b b*; and if there be a depression, then the surface is convex upwards, as at *c c*. Whenever, therefore, a tube of narrow diameter is placed in a fluid, if the action of the particles of the tube on the particles of the fluid be less or more than the attraction of these last for each other, motion ensues, and the fluid falls or rises to a height determined by the diameter of the tube.

Fig. 4.

22. If the tube be perfectly cylindrical, as *Fig. 5*, *a a*, and there be conveyed into it a short column of fluid *b b*, it will be found that this fluid rests in any position, provided the tube be horizontal. But if the tube be conical instead of cylindrical, as in *c c*, and a little column of fluid, *b b*, be introduced into it, then a motion of the whole drop ensues, the progress being made towards the narrow extremity. In this way capillary attraction is competent to produce motions of various kinds.

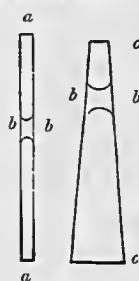


Fig. 5.

23. All these disturbances of ordinary level, and these motions, are found to result from the action of the surface of the liquid. From a consideration of these disturbances, LAPLACE deduced his theory of capillary action; a theory which, with a little modification, is now generally adopted. The thickness or thinness of the tube has no effect whatever on the phenomenon; nor does the substance of which it is composed exert any influence. Every thing is made to depend on the figure of the bounding surface, which necessarily acts more and more powerfully as the diameter of the vessel becomes narrower.

24. Capillary attraction does not take place only between solids and fluids; it is exhibited when solids alone are made use of. In virtue of this power, two pieces of lead cohere with great energy to each other, as also is the case with two planes of polished stone, or plates of glass. When glass is used, electricity of very high tension is readily detected, one of the pieces being positive and the other negative, it would, I suppose, hardly be denied, that the force operating in the case of glass is also the force that operates in the case of stones. Is it not, then, a legitimate supposition, that the adhesion of two pieces of lead is brought about by the same agent, whose presence is masked by the high conducting power of the metal?

25. Between solids and gases capillary action likewise takes place. On the surface of all kinds of solids atmospheric air remains in a state of condensation, as is made evident when such bodies are placed beneath water under an exhausted receiver; the air appearing in copious bubbles, studding the surface of the metal.

26. Now, having a power, the operation of which over inorganic masses is so extensive, it is for us to enquire how far the phenomena of organic systems depend upon its working. Those numerous pores and pipes, and capillary vessels, which abound in all kinds of living structures, but of whose action we are so ignorant, point out to us capillary attraction as one of the great forces in play, determining all kinds of motions and physical changes. To identify the force producing motion of a mechanical character, with that effecting physical change, gives a unity to the action of powers which have hitherto been multiplied without avail, and stamps simplicity and symmetry on actions that are very diverse.

27. Hitherto we have treated of capillary attraction as a force producing certain simple results, as the adhesion of pieces of metal, or of plane solids to the surface of fluids, or the rise or fall of fluids in tubes. All these consist of binary arrangements; and it is probable, as will hereafter be shown, that certain simple processes in the organic kingdom are examples of similar simple forms of action. But, arrangements of a more complex character may be imagined, and are known to exist, where, instead of there being two, three or more elements are concerned. Ternary arrangements lead to the consideration of the doctrine of endosmosis, by which we understand the passage of two fluids or gaseous bodies through a narrow channel, in opposite directions, at the same time.

28. The law of horizontality of fluids meets with a remarkable exception when the containing vessel is a capillary pipe, as has been already stated; for a change of level ensues, according as the fluid will or will not wet the walls of the tube. Laplace has shown that the immediate cause of this rise or fall is the peculiar figure of the surface of the liquid in the pipe. The theory embracing these facts will be found in the supplement to the tenth book of the *Mécanique Céleste*. M. Poisson, from a consideration of the heterogeneity of the liquids in ternary arrangements, has endeavoured to refer all the phenomena of endosmosis and transudation through tissues to common capillary attraction, but with a want of success not usual to the labours of that excellent mathematician; not that we are to deny the result to which he has arrived, for that is only the expression of a fact, but the steps of his investigation are unquestionably faulty, for the

same reasoning will apply to tubes of all diameters, and it does not satisfy the condition that both liquids shall pass in opposite directions at the same time.

29. It is not necessary to proceed here to the discussion of the remoter data of the mechanical part of this question, nor to refer to the elementary conditions of pressure upon a surface, nor to the action of solid bodies alone; though in each of these cases the investigation might readily be carried out to the conditions of motion and repose. Let us proceed to investigate the case where two fluids are adjacent to each other, but do not communicate, except through a pore. This case involves the theory of tissue action. Taking for granted the theory of Laplace, of the equilibrium of liquids in capillary tubes, we may assert,

1stly. That if two fluids *A*, and *B*, whose attraction for each other is greater than the cohesion of the homogeneous particles of either, communicate with each other through a pore, the walls of which attract the one more than the other, motion through that pore will ensue, both liquids passing at the same time in opposite directions.

2ndly. If we take particles receding from the axis of the pore, the forces solliciting any one of them to move in a direction with the axis, gradually decrease, whilst the rectangular forces increase in intensity.

3dly. In the axis of a pore any two molecules, *a* and *b*, situated in the fluids *A* and *B* respectively, are acted upon by two systems of forces—one tending to produce motion parallel with the axis, and the other at right angles to it. The forces which tend to produce motion parallel with the axis are not compensated, but all the rectangular forces compensate each other.

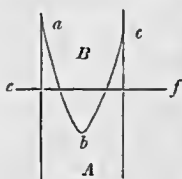


Fig. 6.

4thly. Let *a b c*, Fig. 6, be a section of the figure of the surfaces of the fluids *A* and *B* on contact, and through any part of it, *e f*, let an imaginary plane pass. Now, the forces which act on the side *A* of the plane tending to produce motion in *B*, are much greater than the forces on the other side tending to restrain it. Moreover, the action of these forces is at a maximum at the point *b*. The figure of contact, therefore, becomes changed, the point *b* advancing along the axis, and making the opposing particles retire in the directions of least pressure; the fluid *B* continuing to pass down the axis of the pore; and the very same reasoning shows that at the same time *A* will pass in the opposite direction. If, therefore, two fluids are on opposite sides of a barrier, and only communicate with each other by a pore through it,

motion in that pore will ensue, both liquids passing in contrary directions, simultaneously and cu-axially.

5thly. And the same reasoning which applies in the case of a pore, will also apply to a cribriform plate or tissue, whose apertures are all capillary tubes.

50. In this view of the subject, as is evident, I have imputed the phenomena of tissue action to the force of capillary attraction, taking into account the heterogeneity of the system of fluids. I have not spoken of the relative difference of cohesive force, which, as might be shown, aids in producing the very same results. From these considerations we can deduce the condition of equilibrium, for it is evident that as soon as the chemical composition of the fluid on each side of the pore becomes identical, the forces soliciting motion each way, antagonize each other completely. It was the heterogeneity of the fluids that gave rise to the first movement, and kept it up; but so soon as the media on each side became homogeneous, motion ought to cease; and that this is the case, is abundantly proved by experiment.

51. With respect to the diameter of pores, there are some important conditions. Let *a b c*, Fig. 7, be a pore, whose diameter exceeds double the radius of the sphere of sensible attraction of its own particles; or, in other words, whose axis is beyond the influence of the attractive force of its own walls. If a cylindrical column of fluid, *e f g*, of a certain diameter, moves through it, the circumferential parts of that cylinder will be brought under the direct influence of the walls of the pore, but its axial portions only indirectly through the intermedium of the cohesion of the fluid itself. We may say, therefore, that the axial portions of such a cylinder are unaffected by the pore itself; but if the diameter of the pore be supposed continually to diminish by degrees, all parts of the cylinder will at last be brought within the influence of the walls of the pore. Another mode of viewing this condition of things may place it in a still clearer light. When a liquid rises in a capillary tube of certain diameter, only those portions are under the direct influence of the attractive force of the tube which are nearest to it, the central columns being entirely unaffected; as, when water jets out through a narrow pipe, it is only those portions that are directly in contact with the sides of the pipe that are subject to its resisting influences, any disturbance which the central particles feel arising only indirectly from their cohesion. A pore in a piece of charcoal may suffer a column of water to go through it without in anywise affecting the central portions of that column, by reason of its size; but should the diameter

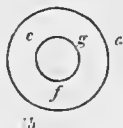


Fig. 7.

of the pore be made to decrease, it is obvious a limit might finally be reached, when every particle that passed should come under the direct influence of the physical force of the pore, and none pass by mere leakage or oozing. The importance of this element, viz: the variability of the diameter of the pore, is greatly to be insisted on. It has heretofore been pointed out in this Journal, and in the Journal of the Franklin Institute, but does not seem to have attracted that attention which it deserves. Chemists are still in the habit of co-ordinating the passage of liquids, through stucco plugs and pervious barriers, with that through tissues and liquids. Physiologists carry out the same error, in supposing that there is no essential difference in the motion of fluids in the capillaries and through the pores of tissues.

32. It is not alone in the vital functions that we meet with applications of the principles of capillary action; the mechanical functions furnish numerous instances. The organs of progression of some animals which delight to walk upon water, are provided with an apparatus of hair, calculated to repel that fluid; hence gnats and certain other insects have no difficulty in passing over the surface of water. By the same means the hydra suspends itself, without effort, in that element; for having exposed for a time the extremity of its foot to the air, so that it may become dry, it, by repulsion, forms a cup-shaped hollow around it, the head of the insect hanging down in the water beneath.

33. Organs of exhalation and absorption are unquestionably capillary systems. The stomata of plants, which botanists suppose to discharge these functions, are of this character; they furnish a well marked instance of the accommodation of apparatus to suit physical conditions. Plants growing beneath the surface of water have no stomata; but if, by any means, they reach the atmosphere and vegetate in it, these organs are produced for the purpose of discharging, under the new order of things, offices which were accomplished by other means. The spongiules of roots, acting as capillary systems, drive the fluids they absorb from the earth, through the tubular vessels of trees, with a force of several atmospheres, extending themselves at a due distance from the trunk, where they may meet with the water that falls from the leaves. In some orders of living things, which are not accommodated with distinct orifices for the reception of food, nutrition is accomplished by capillary systems. In this manner the *porifera* expose a wide surface to the seas, and draw in nutrient matter through their microscopic pores, discharging the surplus as excrementitious matter through their papillary orifices.

34. Like the lungs of the mammalia, the leaves of trees are respira-

tory organs, composed of capillary systems; their mechanical functions are not so complete, though their chemical functions may be identical. They demand no nervous cords to be spread upon them to give them motion and keep up their play; the breezes in which they tremble perform the office of carrying off the exhaled impurity, and the rays of the sun furnish them with their vital force, enabling them to effect the decomposition of carbonic acid, and provide a store of carbon for the purposes of the economy.

35. In identifying the mechanical with the chemical force of organic structures, we see another proof of that unity of design existing through the entire range of living things. Functions of all kinds are accomplished by arrangements of every sort in different classes, yet no one will deny that they all follow one original type. Digestion, as it takes place in the stomach of man, appears a highly complex phenomenon, depending, as some say, partly on the tissue action, partly on nervous and partly on other powers. But are not analogous changes wrought without all this complexity of apparatus in the hydated, which may be taken as the elementary type of the stomach; or in the tænia, which is a colony of stomachs? The polygastric infusorials, some of which have hundreds of these organs, and even the mammalia, do not digest more perfectly than the hydra, a carnivorous polypus, which may be turned inside out without detriment. The laws of digestion, followed by the one, are followed too by the other. If the organ of the one respects the presence of living matter, and refuses to act on it, so does the other; yet the one is furnished with a highly complicated assemblage of muscular bands, of glandular apparatus, of blood-vessels, of nerves, and the other is not.

36. In the higher orders of life processes are carried on by multiplied apparatus, without, however, deviating from the principle of the original simple type. The gift of a new faculty, or the addition of a new organ, brings with it a corresponding change in the arrangement of the whole plan. An engineer, who wishes to adopt a machine to the execution of some new task, alters every part, no matter how remote it may be from the acting point, until every wheel and lever executes its work co-ordinately with all the others; the prime mover remains unchanged, though the general character of the machine may have undergone a renovation; and as all machines, no matter of how many parts they are composed, nor of how many wheels they consist, nor how intricate soever may be their resulting motions, may have their power reduced to and represented by a simple lever, so also organic functions, though often brought about by highly complex arrangements, find simple representatives in the lower orders of life.

A concentration, or a developement of any organ, is often demanded by change in a remote part of the fabric, when even the connexion may not be very evident. Animals, consisting simply of digesting cavities, require no vascular system for propelling or containing a nutritious fluid; they are not in need of separate tissues, devoted to its oxygenation, nor of an insulated respiration, nor do they demand distinct biliary organs; when the nutritious chyle is produced in the stomach of zoophytes, it finds its way into the intercellular spaces, and there circulates without vessels, undergoing through the external tegument the chemical changes. In many insect tribes, the bronchial tubes are spent upon the peritoneum, and respiration takes place directly upon the alimentary canal. With modification of functions, change of external figure is always involved; and as these progress together, systems of living things are constructed, referrible to one common original type. It is thus, in the echinodermata, we trace up successive steps, from the sea urchin to the asterias, and from that to the pentacrinite; a developement of the same parts of the structure continually taking effect, until the extremes bear no sort of resemblance to each other.

37. Had the production of living things been effected by the operation of second causes, we might look with LAMARCK, for some law of successive developement, which should contain the origin of each order and species. We might regard the rudimentary teeth of whales, or the subcutaneous feet of the ophidia, as abortive results of such a law. Considering the brain as a developement of the spinal axis, we might trace in the form of the cranial bones, a developement of a system of vertebræ, brought about as a consequence of the very same laws. We might run a parallel of analogies, between the crustaceous and vertebrated animals, and exogenous and endogenous plants; we might take the cephalopodous mollusks, as furnishing the first rudiments of an internal skeleton, and trace its increasing complexity to meet certain ends, until its perfect developement in the mammalia. In this latter class, we might dwell upon the uniform existence of seven cervical vertebræ, as giving evidence of a persistence in the plan of structure, in species so remote from each other, as the cameleopard, the whale and the mole. Parting from the dorsal vessel of insects, the first rudiments of an aorta, we might follow out the complications of the higher arterial systems. In all the varieties of respiration, whether aquatic, aerial, or mixed, we might see the reproduction of one original chemical design, and in every instance of a concentration of machinery or functions, we might find an impress of the action of external formative agents.

Hampden Sydney College, November 20th, 1837.